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# Design of a reaper for use under Chinese conditions

Yao Chiang  
*Iowa State College*

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DESIGN OF A REAPER FOR USE UNDER CHINESE CONDITIONS

by

Yao Chiang

A Thesis Submitted to the  
Graduate Faculty in Partial Fulfillment of  
The Requirements for the Degree of  
MASTER OF SCIENCE

Major Subject: Agricultural Engineering  
(Farm Machinery)

Signatures have been redacted for privacy

Iowa State College  
1948

## TABLE OF CONTENTS

|  | <u>Page</u> |
|--|-------------|
| INTRODUCTION. . . . .  | 1           |
| CHINESE AGRICULTURE AND THE NEED<br>OF A REAPING MACHINE. . . . .                      | 3           |
| Chinese Agriculture. . . . .   | 3           |
| Farm population . . . . .  | 3           |
| Size of field and farm. . . . .  | 4           |
| Land ownership. . . . .  | 4           |
| Dykes around the boundaries of fields . . . . .  | 4           |
| Percentages of food supply from<br>various crops . . . . .                             | 5           |
| Main agricultural regions . . . . .  | 5           |
| Labor requirement for growing crops . . . . .  | 6           |
| Amount of man labor required for each<br>operation of growing rice and wheat . . . . . | 6           |
| Agricultural labor shortage . . . . .  | 6           |
| The Need of a Reaping Machine. . . . .   | 8           |
| INVENTION AND DEVELOPMENT OF REAPING MACHINES . . . . .                                | 9           |
| Hand Tools. . . . .  | 10          |
| The First Reaper . . . . .   | 11          |
| English Development. . . . .   | 11          |
| American Development . . . . .   | 12          |
| REVIEW OF REAPING MACHINES USED IN CHINA. . . . .                                      | 15          |

|  |     |
|--|-----|
| DESIGN AND CONSTRUCTION OF THE REAPER<br>FOR USE UNDER CHINESE CONDITIONS. . . . .         | 18  |
| Functions of the Reaper. . . . .   | 18  |
| Requirements of the Reaper . . . . .   | 18  |
| Description of the Designed Reaper . . . . .   | 20  |
| Prime motive power. . . . .  | 21a |
| Framework . . . . .  | 24  |
| Cutter bar assembly. . . . .   | 27  |
| Platform. . . . .  | 28  |
| Basket. . . . .  | 30  |
| Reel. . . . .  | 34  |
| Transmission of power to sickle,<br>roller of canvas conveyor, basket<br>and reel. . . . . | 37  |
| Dividers. . . . .  | 48  |
| Shoes . . . . .  | 48  |
| Balancing weight. . . . .  | 48  |
| FIELD TRIALS. . . . .  | 50  |
| DISCUSSION. . . . .  | 55  |
| SUMMARY . . . . .  | 57  |
| LITERATURE CITED. . . . .  | 59  |
| ACKNOWLEDGMENTS. . . . .   | 61  |

## LIST OF TABLES

| <u>Table</u>   | <u>Page</u> |
|--|-------------|
| 1. Percentages of the Food Supply from Various Crops in China. . . . .                                 | 5           |
| 2. Man and Animal Labor Requirements per Hectare for Growing Various Crops in China. . . . .           | 6           |
| 3. Percentage of Man Labor Required for Each Operation of Growing Rice and Wheat . . . . .             | 7           |
| 4. Agricultural Labor Shortage in China (260 Localities, 169 Hsien, 201 Provinces, 1929-1933). . . . . | 7           |
| 5. The Pull Required in Pounds per Foot of Width or Draft per Foot of Field Machines . . . . .         | 22          |
| 6. Draft and Horsepower of Different Mowers at a Speed of Two Miles per Hour . . . . .                 | 23          |
| 7. Power Requirements of Field Machines. . . . .   | 24          |
| 8. Speed of Grain Conveyor on Binders. . . . .   | 30          |
| 9. Comparative Statement of Speeds of Sickle Bars in Harvesting Machines . . . . .                     | 39          |

## LIST OF FIGURES

| <u>Figure</u>   | <u>Page</u> |
|---|-------------|
| 1. Reaper Assembly. . . . .   | 21b         |
| 2. The General Layout of the Frame Work . . . . .   | 25          |
| 3. Side View of the Reaper. . . . .   | 26          |
| 4. Front View of the Reaper . . . . .   | 26          |
| 5. Platform with three Rollers and two<br>Canvas Conveyors. . . . .                         | 29          |
| 6. Basket. . . . .  | 33          |
| 7. Reel, Reel Supports and Bearings . . . . .   | 35          |
| 8. Parts of the Self-aligned Bearing. . . . .   | 36          |
| 9. Reel Drive . . . . .   | 36          |
| 10. The Driving Arrangement. . . . .  | 40          |
| 11. Transmission of Power to the Sickle. . . . .  | 40          |
| 12. Transmission of Power to the Roller. . . . .  | 42          |
| 13. The Turning of a Basket Automatically<br>Controlled by the Weight of Cut Grain. . . . . | 42          |
| 14. Transmission of Power to the Basket by<br>Use of Geneva Wheel. . . . .                  | 45          |
| 15. Transmission of Power to Basket by Use<br>of Ratchet Mechanism . . . . .                | 47          |
| 16. Two Steel Shoes. . . . .  | 49          |
| 17. Two Wooden Boards. . . . .  | 52          |
| 18. The Reaper during the Field Trial. . . . .  | 52          |

## INTRODUCTION

China not only recognizes the need for mechanization but is going the necessary step further by making plans to satisfy the need by whatever methods will bring the best and quickest results.

What is the meaning of mechanization? Mechanization is the process of utilizing power. The progress of agriculture is the result of the increase in the use of power on farm.

Farmer's power plant includes windmills, steam engines, stationary engines, motor trucks, electric motors, and the two most important motors--(1) tractors and (2) animals. Among these, only animals are widely used in China and windmills used locally. If it is necessary to realize the agricultural mechanization in China the kinds or quantity of power used by farmers must be increased. In this way the tractor, one of the two most important farm motors, should go to the farm as the farmer's main helper.

In general, tractors may be divided into two types, farm tractors and small tractors. Between these, which one is suitable for Chinese conditions? Yu (1947) indicated that only the small tractor is needed to cope with the situation presented in Chinese agriculture. The author also had made a study on the adaptation of these two tractors in the summer



of 1947 at Nanking, China, and got the result that the small tractor was more easily accepted by the farmer than the farm tractor.

How many attachments does a small tractor have? Plow, harrow, planter, cultivator and mower are the most common attachments. Among all the operations of rice and wheat cultivation, harvesting always shows the most severe case of labor shortage because the large acreage of the crop must be harvested within a limited period. Any delay in reaping at the correct time increases the grain loss sharply. The farmer usually has to pay the highest wages to get enough helpers because during the harvesting season all the available labor is busy in reaping.

Under the agricultural conditions in China, small tractors should have a reaper as their one important attachment for not only reducing the cost of harvesting, but also for changing the character of labor. The purpose of this research work is to try to make a proper reaper connected to a small tractor for reaping rice and wheat under Chinese conditions.



## CHINESE AGRICULTURE AND THE NEED OF A REAPING MACHINE

### Chinese Agriculture

#### Farm population

In comparison with that of the United States, Chinese agriculture is almost entirely different, both in practices and in farming systems. The basic difference is in the density of population (Tsou, 1944).

China is predominantly an agricultural country. With a gross area of almost three billion acres (including Tibet and Mongolia), only 12 percent of this area (230,000,000 acres) is under cultivation. The total population is 450 million, 80 percent of which are engaged in farming.

The farm population per square mile of crop area is found to vary from 900 to 1,900, some settled districts having as many as 4,000 persons. The awkward balance between the vast total land area and the small farming land and between the total population and the large percentage of people on the farms has produced the inevitable result of small farms. It has been figured that in China it takes three farmers to feed themselves and one non-farmer, whereas in America, the other end of the extreme, one farmer produces for himself and six non-farmers.

### Size of field and farm

The size of the unit field is small. Rice fields are especially smaller than the fields used for raising other crops, for it is easier to level and control the water flow over small areas.

The usual size of farms is only four acres (Buck, p. 286, 1937).

### Land ownership

All the land of each farm is divided into several fields which are usually not adjoining each other. That makes for the fragmentariness of land.

### Dykes around the boundaries of fields

The dykes around the boundaries of the fields are high and narrow, especially in the rice area. Under these mentioned conditions a small tractor would be better adapted than would a farm tractor.

Solely from the standpoint of the efficient and economic use of machinery the farm tractor is no doubt preferable, but the difficulties of bringing about the changes necessary to permit the economic use of "large" (farm tractor) equipment are many: increasing the size of fields, changing planting methods, changing the pattern of land ownership, etc. Therefore, no rapid or general change can be anticipated.

On the other hand, small tractors and their attachments which are more suitable to the small fields and more easily transported may be introduced with less need for any radical change in the pattern of land ownership. That is the reason the small tractor is preferable as the power unit in China.

Percentages of food supply from various crops

According to the estimation of Dr. P. W. Tsou (1945), the percentages of the food supply in China from various crops are shown in Table 1.

Table 1

Percentages of the Food Supply from Various Crops in China

| Crops    | Percentages |
|----------|-------------|
| Rice     | 27          |
| Wheat    | 21          |
| Kaoliang | 17          |
| Millet   | 16          |
| Corn     | 9           |
| Others   | 10          |

Main agricultural regions

Dr. J. L. Buck (p. 30, 1937) classified the Chinese agricultural area into two regions; namely, wheat region, area 448,174 square miles; rice region, area 913,731 square miles.

Labor requirement for growing crops

The man and animal labor requirements per hectare (2.471 acres) for various crops in China (Buck, p. 320-24, 330, 1937) are shown in Table 2.

Table 2

Man and Animal Labor Requirements per Hectare for Growing Various Crops in China

| Crops    | Labor requirements (day) |        |
|----------|--------------------------|--------|
|          | Man                      | Animal |
| Wheat    | 93.0                     | 23.8   |
| Rice     | 157.8                    | 38.2   |
| Barley   | 112.3                    | 29.0   |
| Corn     | 102.4                    | 16.9   |
| Soybean  | 97.0                     | 23.6   |
| Millet   | 103.9                    | 23.4   |
| Ksoliang | 99.3                     | 23.6   |

Amount of man labor required for each operation of growing rice and wheat

Percentage of man labor required for each operation of growing rice and wheat is shown in Table 3 (Buck, p. 320-24, 1937).

Agricultural labor shortage

The agricultural labor shortage in China is shown in Table 4 (Buck, p. 312, 1937).

Table 3

Percentage of Man Labor Required for Each Operation  
of Growing Rice and Wheat

| Operation     | Labor |       |
|---------------|-------|-------|
|               | Rice  | Wheat |
| Plowing       | 10    | 11    |
| Harrowing     | 5     | 6     |
| Fertilizing   | 8     | 12    |
| Planting      | 14    | 9     |
| Cultivating   | 18    | 14    |
| Harvesting    | 10    | 16    |
| Threshing     | 9     | 14    |
| Miscellaneous | 26    | 18    |
| Total         | 100   | 100   |

Table 4

Agricultural Labor Shortage in China (260 Localities,  
169 Hsien, 201 Provinces, 1929-1933)

| Operation   | Percent of localities report-<br>ing labor shortage |             |
|-------------|---|-------------|
|             | Wheat region  | Rice region |
| None        | 15  | 22          |
| Harvesting  | 78  | 57          |
| Cultivation | 17  | 8           |
| Planting    | 16  | 34          |
| Irrigation  | 2   | 21          |



### The Need of a Reaping Machine

All the items above have pointed out that in China rice and wheat are the two main crops, that the labor requirements per hectare for both man labor and animal labor on rice or wheat culture are higher than that for any other crops, and also that the labor shortage is especially felt during the harvesting period.

At present the farmer and his family cannot harvest their crops alone. They depend on outside help which is very uncertain and unreliable under ordinary conditions. Enough help may be secured, but sometimes the crop becomes dry and shelled out due to lack of harvesters.

There is a proverb in China which says that, "harvesting wheat ought to be done as quickly as putting out a fire." The harvesting of grain has been the most burdensome and exacting operation on the farm. It must be done at the right time and may not be delayed like other work, for if not promptly done the farmer may lose all the fruits of his previous labor. Chinese farmers are really anxious to have a proper reaping machine.

## INVENTION AND DEVELOPMENT OF REAPING MACHINES

"The twig planted by British inventors, nourished and intelligently cultivated by practical genius, had in 1850 become a well-rooted, vigorous sapling; thereafter, it grew rapidly, putting forth limbs and branches in various directions", said Ardrey (p. 47, 1894). As soon as it had been demonstrated that grain could be successfully harvested by machinery, inventors directed their attention to its delivery, to provide mechanical methods for getting it off the reaper in the best possible shape for binding; the various self-rakes and droppers were then invented.

A practical reaper was produced by degrees. One man invented a machine having, perhaps, only a single useful feature; his machine died, but this feature lived. Another did likewise and still another did, too, and so, as the years rolled along, the useful features became massed until practical machines contained them all and the successful reaper was invented not by one man, but by many.

In making a study of the invention and development of reapers, we find that nearly all progress along this line has been comparatively recent. One hundred years ago the farmers were still using the same kind of harvesting tools that farmers in Bible times used.



### Hand Tools

There is no record of any machine constructed to reap grain otherwise than by hand until about the close of the last century (Ardrey, 1894). The people of early times were provided with crude hand tools for the reaping of grain. These primitive sickles or reaping hooks were made of flint and bronze or with a wooden handle and iron blade. It was the most up-to-date method of cutting grain from early times until the latter part of the eighteenth century. One man with a sickle could cut from one to one and a half acres in ten hours.

The first step in advancement came in the latter part of the eighteenth century when the sickle was made into a scythe, the blade being lengthened and the handle being adapted so that both hands could be used.

The cradle was developed from the scythe by adding fingers to keep the straw straight. The time of this introduction was somewhere between 1776 and the close of the eighteenth century. One man could cut from two to four acres per day.

All of these hand tools are still the implements used for cutting grain and grass in many places where conditions are such that reaping machines are impracticable or have never been introduced.

### The First Reaper

Pliny, writing in the first century A.D., described a reaping machine used in Gaul. It consisted of a large comb attached to the front of a two-wheeled box which was pushed along by an ox. The comb was run through the corn just below the heads, and a man walking beside the machine swept the heads backward, so that they were broken off and gathered into the box.

### English Development

a. Before 1806 there were several attempts at the design of a reaping machine, but none were successful.

b. 1806 - Gladstone invented a machine. In his machine the horse walked at the side of the grain and, hence, the introduction of the side cut resulted. It had a revolving cutter, a crude form of guard, an inside and outside divider, a platform, and a hand rake. As a whole this machine was not successful.

c. 1808 - Salmon of Woborn invented the reciprocating cutter, which acted over a row of stationary blades. This machine combined reciprocating and advancing motion for the first time. The delivery of the grain was unique in the fact that a vertical rake actuated by a crank swept the grain from the platform upon which the grain fell after being cut.

d. 1812 - John Comson of Alnwick submitted a model of

a reaper to the Royal Society of Arts. This machine had an angular reciprocating knife in a finger-bar and was driven from a live axle through bevel gearing, an eccentric and a connecting rod. It possessed the essentials of the modern mower, but never became a commercial success.

e. 1822 - Henry Ogle produced a machine which had a reel (the first reel used) and a dropper.

f. 1826 - Patrick Bell of Carmyllie produced the first successful reaping machine; the original machine may be seen in the Science Museum in London. His machine had oscillating knives, each of which were about 15 inches long and about 4 inches broad at the back. It presented a new idea in having a canvas moving on rollers just behind the cutting mechanism, which carried the grain to one side and deposited it in a continuous swath. He also provided his machine with a reel and inside and outside dividers. His machine continued to be used in some parts for several years until replaced with machines built after the inventions of the Americans, Hussey and McCormick.

#### American Development

a. Before 1833 there were none of any importance.

b. 1833 - Obed Hussey, of Baltimore, was granted his patent which marks the beginning of a period of almost marvelous development. His reaper was principally remarkable

for its compact form, its hinged frame, and for the novel construction of its guard-teeth, which were made double or slotted, so that the scalloped or zigzag knife might vibrate through the openings, the space between each guard, from center to center, being as wide as the distance between each point on the knife or sickle.

c. 1834 - Cyrus H. McCormick patented his first reaping machine. His machine was provided with a reel and an outside divider. The knife had an edge like a sickle and worked through wire. The machine had a cut of about 4-1/2 feet and was drawn by one horse. The grain fell upon a platform and was raked off by a man who used a hand rake as he walked beside the machine.

d. 1851 - Palmer and Williams invented a sweep rake and quadrant platform.

e. 1858 - C. W. and W. W. Marsh gave to the world the Marsh harvester. This carried two or more attendants who received the grain from an elevator and bound it into sheaves.

f. 1869 - John F. Appleby developed the knotter and added a self-sizing device. The Appleby knotter is used on almost every machine today.

g. 1870 - George H. Spaulding invented and was granted a patent on the packer for the modern harvester.

h. Since 1875, improvements have been in details of workmanship rather than in elements. The most important

fundamental development of recent years has been the direct driving of the cutting and binding mechanism through the power take-off of the tractor.

## REVIEW OF REAPING MACHINES USED IN CHINA

In China the method for rice harvesting is using sickles with a serrated blade about six inches long and having a handle one foot in length. The worker grasps one hill of rice (20-30 stalks) in the left hand and with the right hand slices it off about two inches above the ground. The sickle is not swung but is drawn across the stalks like a knife. Frequently, two hills of grain are held together with the left hand and severed, one after the other, with two cuts of the sickle. Then the grain is carefully laid aside in small united bundles (gavels) with the butts even. Adjusting the butts of the bundle (not in tied bundle) is an important part of the duty of the person doing the cutting; even butts are essential when the grain is threshed at the threshing box or by the pedal cylindrical thresher. In general, the rice straw is valued highly and any damage done it is considered objectionable. In some sections farmers use straw as the material for making ropes and covers of roofs. In some sections, however, it is used primarily for fuel and in such regions damage to the straw in threshing would not be a serious detriment.

The expression "cutting" as used here includes the actual cutting of stalks with the sickle, gathering the cut



stalks into bundles with butts even, and laying the bundles down uniformly so as to form a convenient windrow for the threshers or for laying the next gavels down.

The labor requirement for cutting rice with a hand sickle is 0.33 acre per 10-hour day (Stone and Kan, p. 9, 1948).

Two methods of wheat harvesting are used in China; one is using sickles with a smooth blade about seven inches long and having a handle two feet in length. The worker uses his right hand to swing the sickle and his left hand to collect the cut grain. One man could cut one acre per 10-hour day. The second method is using cradles; these are nearly the same as those used in the United States except using of nets instead of fingers. The rate of cutting is from two to four acres per day.

A test of cutting rice with a mower mounted on the front of a garden tractor has been made by Stone and Kan (p. 17, 1948) too. The following are some of the main points quoted from their report.

The windrows made by the tractor are not as conveniently handled by the threshmen as are the carefully placed bundles prepared by reapers using the hand sickle. In the case of hand cutting, the cut grain is carefully formed into gavels, at the time it is cut; the butts and heads of such gavels are even, which is an important requirement when the box is used for threshing.

In the case of tractor use, the cut grain lies in a continuous windrow and is not formed into gavels..... It may be desirable and necessary to attempt the design of a



device that would act as a butt adjuster and release the cut grain in the form of gavels. A bound bundle does not seem necessary or even desirable....

In all the fields cut by the tractor the condition of the surface of the field provided fairly good traction. The tires used on the garden tractor were not good traction tires; they were very small (4.00x8.00) and not provided with raised traction lugs. With tires of proper size and design it is felt that draining the fields about two weeks prior to harvest would give satisfactory traction conditions on a large percentage of the rice land area.

Ramiah (1947) designed a reaper for India. His reaper may be used in China for the agricultural conditions of those two countries are alike, especially in the rice area. The reaper was designed for intermittent motion; in this way the cut grains lying on the canvas conveyor are deposited on the ground to one side of the reaper at intervals in untied bundles. But he suggested that an automatic mechanism, driven through the land wheels and actuated by cams, can be designed to deposit the grains to the side while the machine is in continuous motion. When this is achieved, the performance of his reaper will be as continuous as any other field machine. This alteration not only increases the machine's capacity but will certainly make it more welcome to its users.

A binder could not be used on a small rice field; it would be too difficult to maneuver properly and could be used on wheat area, but the present cost and scarcity of binding twine would prohibit its use.

## DESIGN AND CONSTRUCTION OF THE REAPER FOR USE UNDER CHINESE CONDITIONS

### Functions of the Reaper

A good reaper for use under Chinese agricultural conditions must have the following functions:

1. The reaper must be used to cut both rice and wheat.
2. The reaper must cut the stalks off about four inches above the ground level.
3. The reaper must gather the cut stalks into bundles (about five inches in diameter but not in tied bundle) with even butts and heads.
4. The reaper must lay beside itself the bundles down intermittently on the land so as to form a convenient windrow for the thresher.

### Requirements of the Reaper

Besides the general requirements of a well-designed agricultural machine (Davidson, p. 36, 1931), a reaper for Chinese conditions must have the following essential requirements:

1. Be easy to mount on and to detach from the power unit.

2. Conform to the general construction of the sickle bar, speed and stroke of the sickle and to the successful practices used in combines and binders.
3. Be a real labor-saver. The width of cut of the sickle bar is about 38 inches and this will enable a person to harvest about nine acres per day.
4. Be of light weight so as to be easily transported from one field to another. Framework of the reaper is to be as light as possible without sacrificing rigidity and strength. It may be built of light angle iron and tubular structure. Gas or electric welding are to be used throughout the fabrication except for parts which require removal to be convenient for repairs.
5. Be easy to operate. Since this reaper will be operated by one man who will be walking behind the small tractor, only an extra hand lever is added to the small tractor to control the reaper.
6. Have overall dimensions planned so that a large radius of turning may be avoided.
7. Have sufficiently low cost to permit economic operation.

### Description of the Designed Reaper

Before any kind of reaper is designed the designer ought to read over or take into full consideration the seven essential principles of the Cyrus Hall McCormick reaper (McCormick, p. 17-18, 1931) as a guide. These are:

1. The straight reciprocating knife, whereby the standing grain is attacked by lateral motion as well as by the forward movement of the machine. (This the inventor himself regarded as the most vital of the elements.)
2. The fingers or guards for the knife, which support the grain at the moment of cutting.
3. The reel, which gathers the grain in front of the reaper and holds the heads in place as the fingers hold the stalks.
4. The platform, on which the grain falls to be raked away in a swath.
5. The main wheel, directly behind the horse, which carries the machine and operates gears to actuate the moving parts.
6. The cutting to one side of the line of draft, which permits the horse to walk on the stubble while the cutter bar works in the standing grain.
7. The divider at the outer end of the cutter bar,

which divides the standing grain from that which is to be reaped.

These principles are present in each reaping machine. This experimental reaper was designed according to all the foregoing specifications. Ten different main parts are described as follows and the reaper assembly is shown in Figure 1.

Prime motive power

The "David Bradley" garden tractor was used as the prime motive power. The specifications of the tractor are:

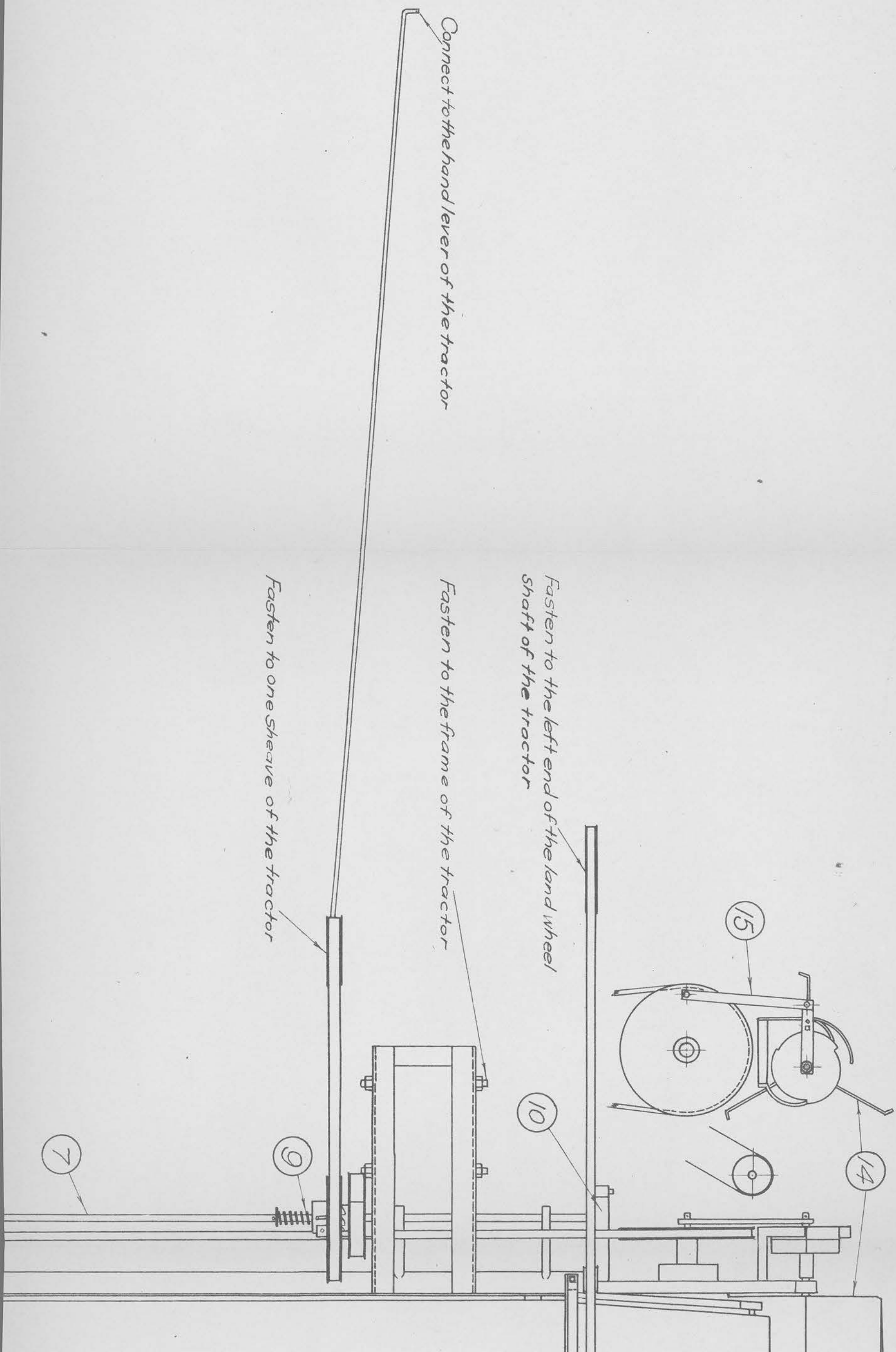
Manual No. 500-306126  
Sears, Roebuck & Co., U.S.A.  
Serial No. 450490, H.P. 1-1/2

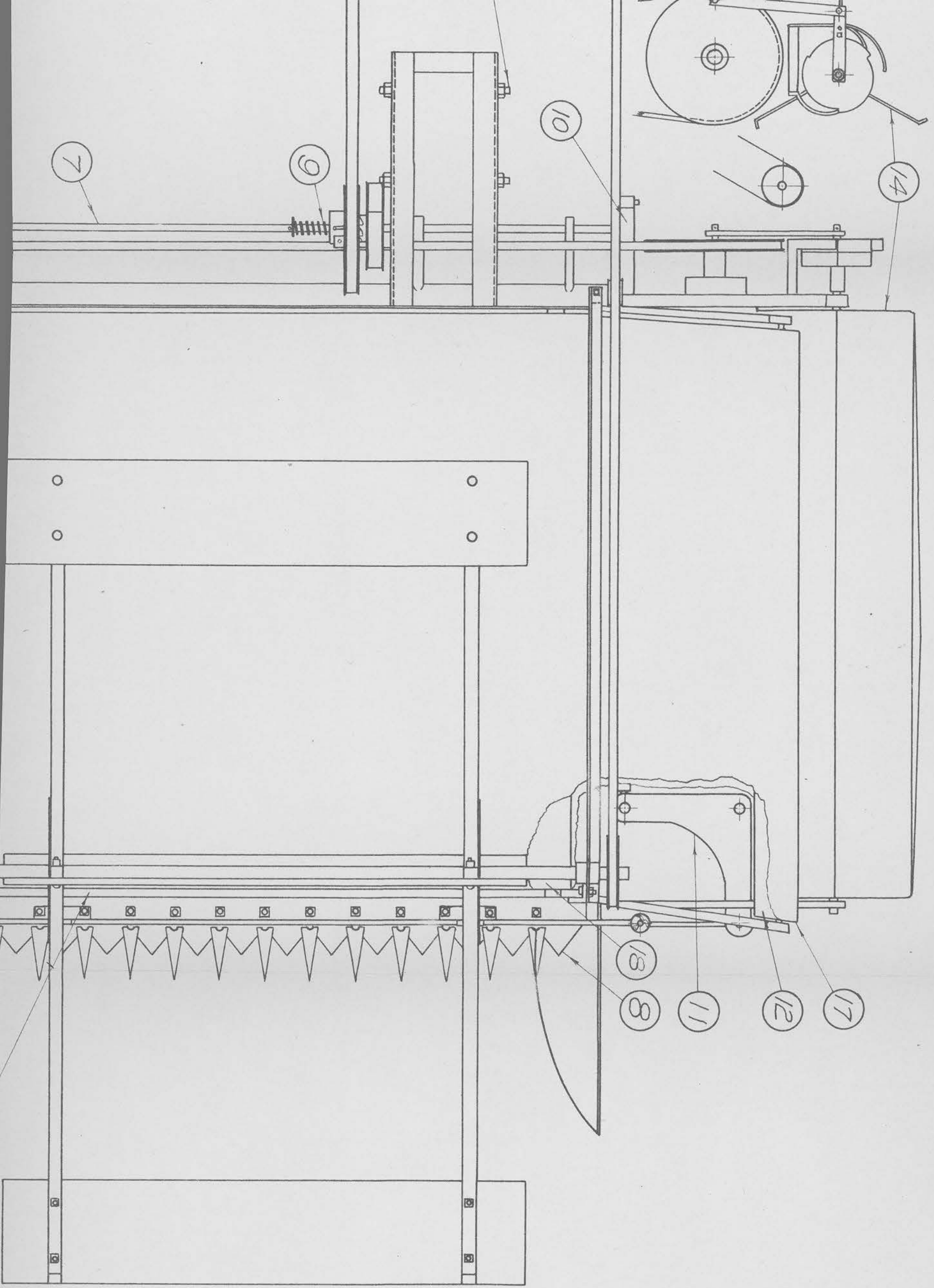
The engine mounted on this tractor was made by the Briggs and Stratton Corporation and it is a Model H rope starter type gasoline engine designed as a standard 1-1/2 H.P. unit equipped with a throttle control and weighs forty pounds.

|                          |   |
|--------------------------|---|
| Bore.....                | 2 inches  |
| Stroke.....              | 2 inches  |
| Piston displacement..... | 6.23 cu. in.  |
| Type.....                | 4 cycle, single cylinder<br>L-head, air cooled        |
| Ignition.....            | Patented high tension<br>built-in flywheel<br>magneto |
| Lubrication.....         | Splash system   |

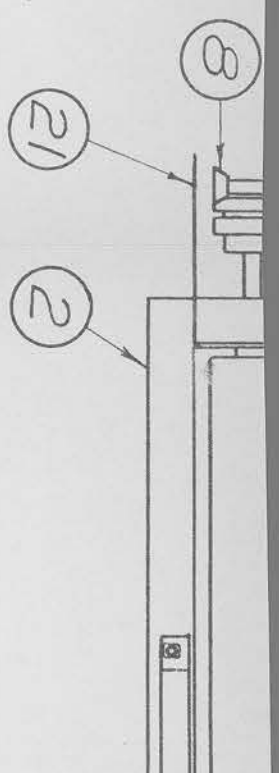
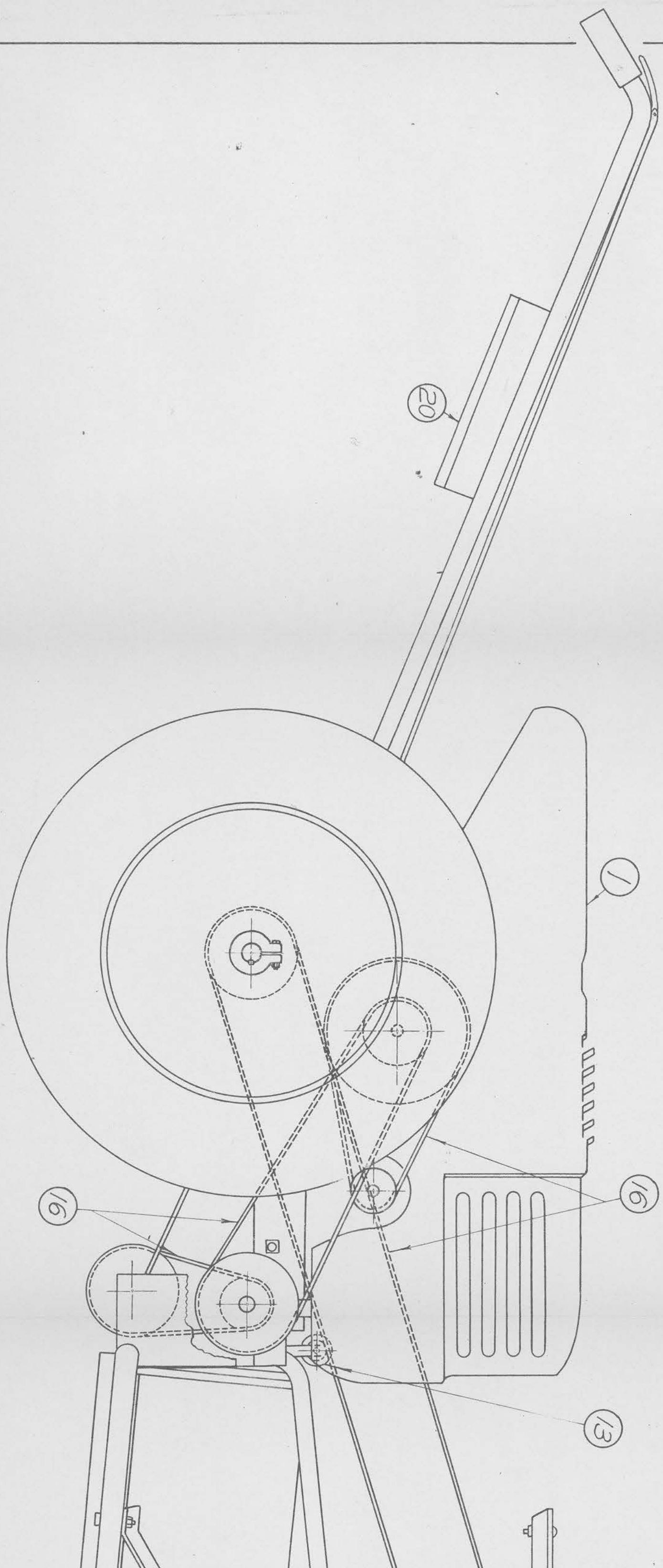
It develops a power of 1.30 to 1.68 H.P. while the speed range is from 2600 to 3600 R.P.M.











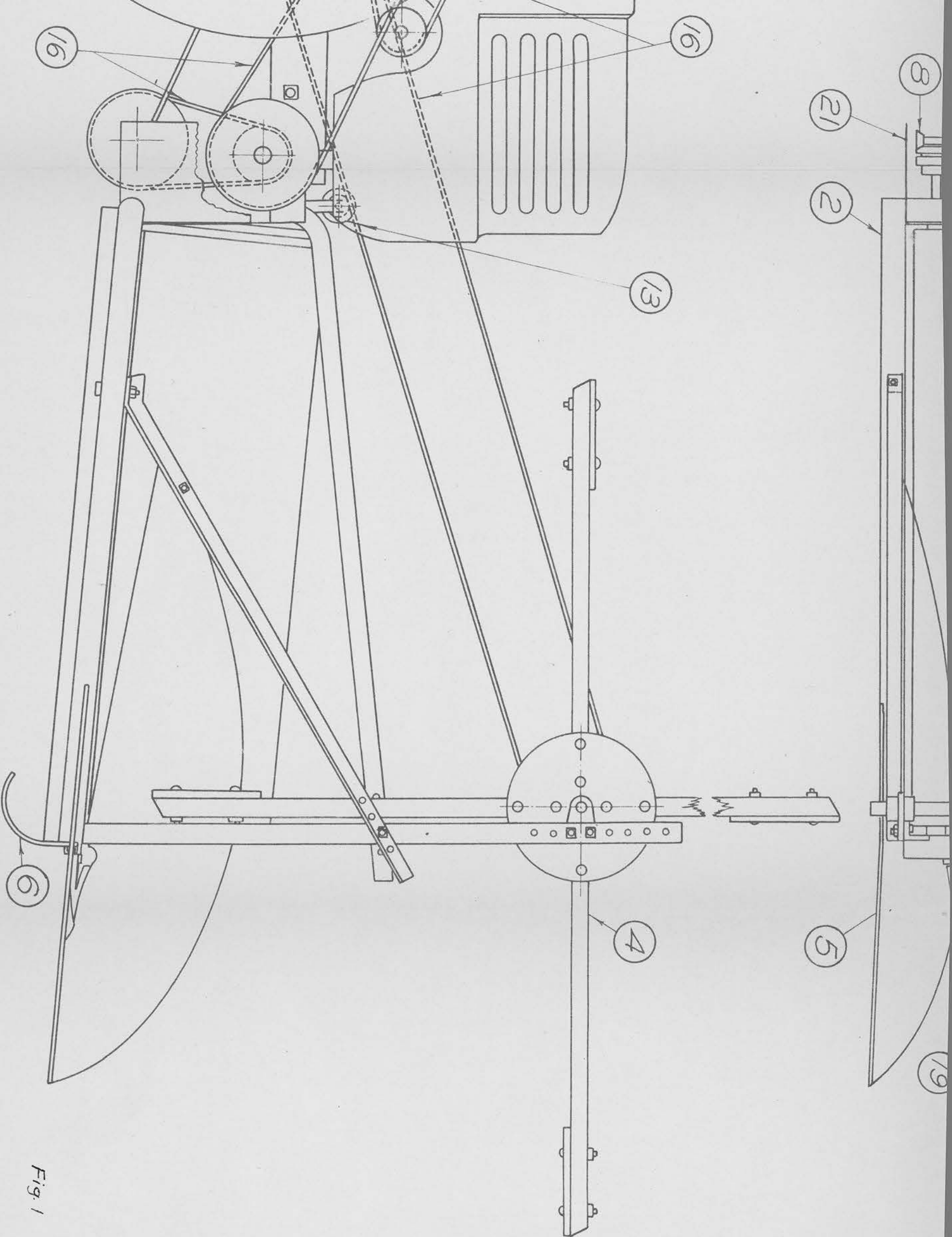


Fig. 1

|  |                                  |   |                    |
|--|----------------------------------|---|--------------------|
| 21   | Fence                            | 1 | Sheet metal        |
| 20   | Weight for balancing             | 1 | C.I. 50            |
| 19   | Support board                    | 3 | Wood               |
| 18   | Inner Canvas conveyor            | 1 | Canvas             |
| 17   | Outer canvas conveyor            | 1 | Canvas             |
| 16   | A section V-belts                | 4 |                    |
| 15   | Mechanism for turning the basket | 1 |                    |
| 14   | Basket                           | 1 | 3/8" Rod, Sheet me |
| 13   | Idler                            | 1 | C.I.               |
| 12   | Roller ( $\phi=2\frac{1}{2}$ ")  | 3 | Wood               |
| 11   | Bell crank                       | 1 |                    |
| 10   | Pitman                           | 1 | Wood               |
| 9  | Transmission unit                | 1 |                    |
| 8  | Bevel gear                       | 2 | C.I.               |
| 7  | Shaft                            | 1 | 3/4" Pipe          |
| 6  | Shoe                             | 2 | Steel              |
| 5  | Divider                          | 2 | Sheet metal        |
| 4  | Reel                             | 1 | Wood & Sheet me    |
| 3  | Cutter bar                       | 1 |                    |
| 2  | Frame                            | 1 | 1/4" Pipe          |
| 1  | David Bradley tractor            | 1 |                    |
| No. Part name & description Req'd Material |                                  |   |                    |

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**REAPER ASSEMBLY**

|              |            |         |              |
|--------------|------------|---------|--------------|
| Dn. by       | Yuo Chiang | Ch. by  | CTOALL       |
| Dr. & Tr. by | Yuo Chiang | App. by | CTOALL       |
| Scale        | 3/16" = 1" | Date    | Oct. 1, 1948 |

For determining the adequate power requirement of an engine, comparison was made to a machine performing similar function and this was the binder. In the calculation of the capacity of the power unit, the high draft has to be considered. Table 5 indicates that the high draft of the binder

Table 5

The Pull Required in Pounds per Foot of Width or Draft  
per Foot of Field Machines

| Machine | Low | High | Normal |
|---------|-----|------|--------|
| Mower   | 55  | 100  | 80     |
| Binder  | 65  | 150  | 100    |

Source: Agricultural Machinery. J. B. Davidson.  
p. 372.

per foot of width is 150 pounds. Based on this draft, 2.4 H.P. is required for a grain binder of three feet width at a speed of two miles per hour, but the reaper designed is comparatively light in construction and has no heavy field wheels. The operator walks with the machine instead of sitting and saves ten pounds of draft. This is shown in Table 6 (Sanborne, 1891). Also, the knotting mechanism is not present. Due to the above reasoning, an engine of 1.5 nominal H.P. was proposed to be used as the prime mover. There is a close agreement of this result with calculations made by Carter (Carter, 1934) in Table 7. It will be seen

Table 6

Draft and Horsepower of Different Mowers at a Speed of Two Miles per Hour

| Name of machine   | Weight of machine: lb | Length: ft | Draft: lb | Draft: lb | Entire draft: lb | H.P. due to weight: lb | H.P. due to weight: lb | H.P. due to weight: lb |
|-------------------|-----------------------|------------|-----------|-----------|------------------|------------------------|------------------------|------------------------|
| Crown             | 585                   | 4-1/4      | 251       | 177       | 10               | 1.33                   | 0.94                   | 0.88                   |
| McCormick Deering | 670                   | 4-1/4      | 260       | 167       | 10               | 1.38                   | 0.88                   | 0.82                   |
| Wood's Tubular    | 550                   | 4-1/4      | 203       | 120       | 10               | 1.08                   | 0.64                   | 0.58                   |
| Champion          | 580                   | 4-1/2      | 267       | 152       | 10               | 1.42                   | 0.81                   | 0.75                   |

Calculated from data available from "Draft of Mowing Machines" by J. W. Sanborne.



Table 7

Power Requirements of Field Machines

| Name of machine | Normal draft per foot of width<br>lbs. | D.B.H.P. required per foot of width at: |       |       |
|-----------------|--|---|-------|-------|
|                 |  | 2 MPH                                   | 3 MPH | 4 MPH |
| Mower           | 80                                     | 0.43                                    | 0.64  | 0.85  |
| Binder          | 90                                     | 0.48                                    | 0.72  | 0.96  |

Source: Technique for selecting Mechanical Farm Equipment. W. H. Carter. p. 80.

that this table indicates 0.48 D.B.H.P. per foot of width of cut in grain binders at the speed of two miles per hour. This corresponds to 1.5 H.P. for a three foot width of cut. These calculations were proved in practice when the machine worked up to expectations.

Framework

The frame must be strong and rigid enough to carry the total weight of the reaper itself and about 30 to 40 pounds of cut grain, and to resist the vibration when working in the field. It must necessarily be simple for ease of fabrication.

Figure 2 shows the general layout of the framework. Figures 3 and 4 show the side view and front view of the reaper, respectively. It was built up of pipes and either light flat steel bars or angles with a view of making the

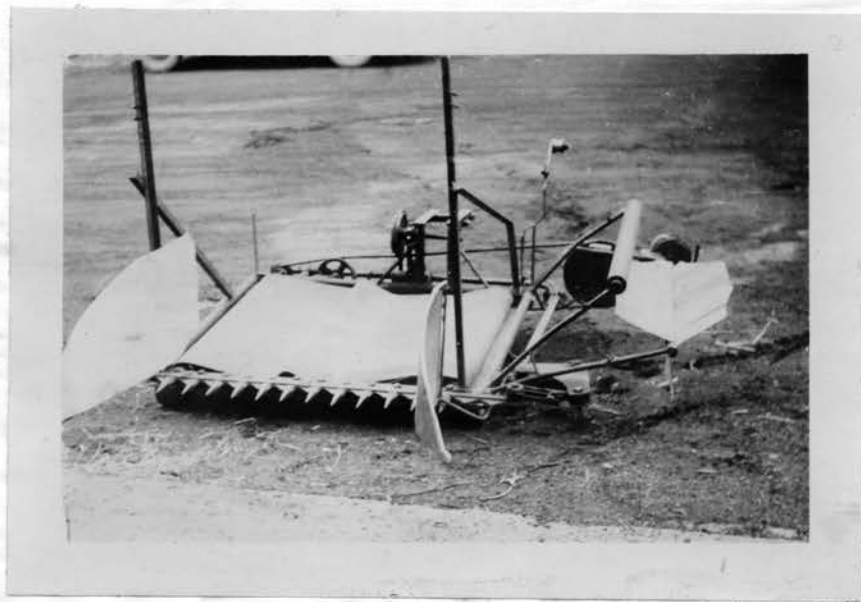


Fig. 2. The General Layout of the Frame Work



Fig. 3. Side View of the Reaper



Fig. 4. Front View of the Reaper



framework easily detachable. Only the cutter bar of 38 inches in length was cut from the used binder.

The cutter bar and three pieces of steel tubing formed a rectangle. At one end of the rectangle, two bearings for one wooden roller were carried; at the other end of it there were two adjustable bearings for another wooden roller. These adjustable bearings were for regulating the tightness of the canvas conveyor.

#### Cutter bar assembly

The construction of the cutter bar was the same as that of the corresponding part of the binder. The guards, guard plates, sickle clips, sickle bar and wearing plates were attached in the same manner and had the same functions. The cutter bar did not drag on the ground. The weight was borne on the wheels and the shoes of the reaper. The bar itself was made of heavy-stock 2-bar angle steel. The guards were bolted to the cutter bar. They were spaced two and one-half inches apart. A 34-inch (effective cut) reaper, therefore, had thirteen guards. The sickle sections were held down against the guard plates by the knife clips. The sections were serrated. Smooth guard plates were used in connection with the serrated sections. This combination gave the best results for cutting grain. The travel of the sickle was five inches, twice the distance between two guards.

At one end, the sickle bar was connected through a short link to the bell crank lever. The other end of the bell crank lever was attached to the pitman shaft. The speed of the sickle bar or the number of strokes of the sickle bar per minute or per foot of travel of the land wheels will be discussed later in the section about the transmission of power to the sickle.

### Platform

Figure 5 shows the platform with the three platform rollers and two platform conveyors in place. The cutter bar was attached to the front of the platform. The inner conveyor (or the short one) put around rollers A and B in Figure 5. The outer conveyor put around the elevated roller C and the whole inner conveyor. The outside roller was driven by the bevel gear and this roller drove the inner conveyor, and the inner conveyor drove the outer conveyor. The inner and elevated rollers were two carriers or "idler" rollers only; that is, they did not drive but only carried the canvas conveyors. The bearings of both the inner roller and the elevated roller were adjustable for tightening the canvas conveyors.

The bottom of the platform was made of sheet metal which was carried on four angle iron cross sills.

To prevent the grain from being blown over the rear of



Fig. 5. Platform with Three Rollers and Two Canvas Conveyors

- A. Outside roller
- B. Inside roller
- C. Elevated roller
- D. Inner canvas conveyor
- E. Outer canvas conveyor

the platform, the platform fence (Fig. 1, No. 21) was used.

As the grain was cut by the sickle it fell on the moving outer platform conveyor which was 36 inches in width (the total height of the grain is 24 to 36 inches) and conducted the grain to a height about 16 inches from the ground and dropped it into a basket (Fig. 1, No. 14).

The speed of the canvas conveyor was about 280 feet per minute on combines and 120 to 180 feet per minute on binders (Wooley, 1926). In this design the speed of 130 feet per minute was adopted.

Table 8

Speed of Grain Conveyor on Binders

| Rate of travel |               | Speed of canvas apron |
|----------------|---------------|-----------------------|
| <u>mi/hr</u>   | <u>ft/min</u> | <u>ft/min</u>         |
| 2.00           | 176           | 120                   |
| 2.25           | 198           | 133                   |
| 2.50           | 220           | 150                   |
| 2.75           | 242           | 165                   |
| 3.00           | 264           | 181                   |

Basket

As the threshing box method is used in China, the cut grain must be deposited on the stubble in even straight windrows, so that it can easily be picked up and gathered into bundles for threshing (Stone and Kan, p. 17, 1948).

Grain heads must all lie in one direction and butts in the other. Butts and heads of the bundles must be even to facilitate threshing. Hence, it is necessary that a proper device for an orderly deposition of cut grain should be incorporated in the design.

Many methods which can be used to collect and deposit cut grain in even bundles (not in tied bundles) on the ground at equal distances are as follows:

1. Use of a stationary platform and the raking of the fallen cut grain in these ways,
  - a. by a hand rake with sufficient head-space for operating the rake without the reel getting in the way;
  - b. by a rake which sweeps automatically;
  - c. by a metal plate traversing on the stationary platform from end to end. This plate is connected to chains and moved on the platform intermittently to rake the cut grain.
2. Use of a canvas apron as the platform moving intermittently,
  - a. by a clutch to control the motion of the apron. When the clutch is engaged the apron will move fast and deposit the cut grain outside. When it is declutched it will stop the movement.
  - b. by a canvas apron which moves very quickly and



drops the grain to one side and then remains stationary for an interval.

3. Use of a canvas apron as the platform moving continuously,
  - a. by a vertical plate at one end of the platform. This plate may be raised or lowered, by the operator or by an automatic mechanism.
  - b. by a tiltable basket at one end of the platform which is automatically tilted when it is full to unload the grain.

Among these, the most effective, perfect and labor-saving method is the last one. The basket was made of three sheet metal plates and one axle (Fig. 6). One edge of each plate was welded to the axle. Three plates were set at an 120 degrees angle to each other. In this way the basket unit was composed of three small baskets. It is the purpose of this basket to collect the cut grain in bundles. After one small basket was filled with cut grain the whole basket unit was quickly and automatically turned at an angle of 120 degrees to unload the grain on the ground and let the next small basket continue to collect its load. In most cases the leaves and stems of cut grain tangled. Here a wedge point (Fig. 6-C) was made on each outer edge of the three sheet metal plates and separated, distinctly, the tangled grain into two individual bundles. At last the even bundles were spaced on the ground at equal distances.

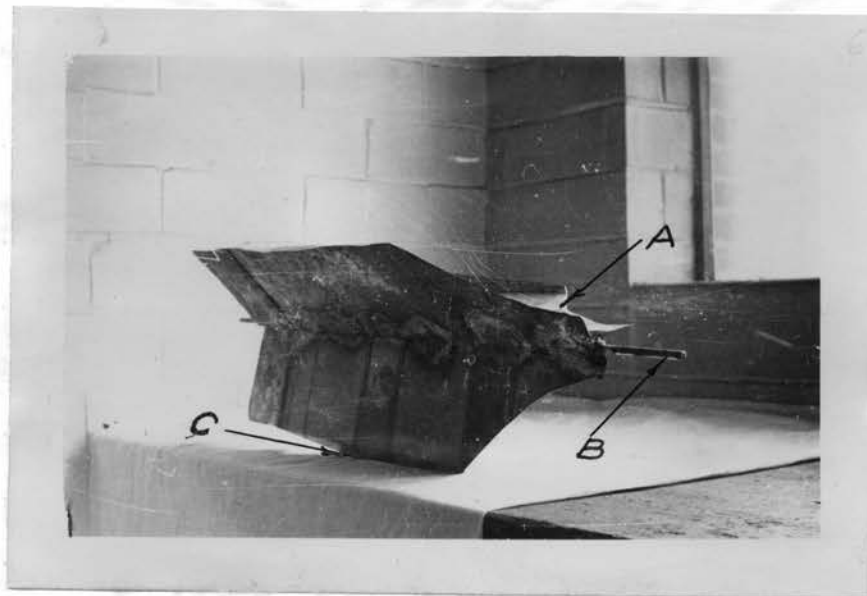


Fig. 6. Basket  
A. Sheet iron plate  
B. Axle  
C. Wedge point

## Reel

The function of the reel is to bend the standing grain toward the sickle and hold it against the sickle until after the grain has been cut. The reel should be raised, lowered and tilted forward or backward so as to meet the many different conditions. The slats must strike the standing grain just below the head and should not leave the grain until after it is cut. Four reel slats were used. In the construction of the reel in this machine there was no deviation from other standard machines. Figure 7 shows the reel, the reel supports and the bearings for the reel shaft.

The two bearings for the reel shaft were a little different from others used in this machine. If the reel supports were not rigid enough, the bearings would be thrown out of alignment when the machine was under the operating conditions. The simple construction of self-aligning bearing used in this machine is shown in Figure 8.

Steel pipe was used as the reel shaft. Two ends of the shaft were supported by two self-aligning bearings. Adjustment for varying the height of the reel was provided by shifting the shaft bearings.

Power for driving the reel was taken from the left drive-wheel shaft of the tractor and was transmitted through a section A V-belt. There was an idler-pulley to take care of the tightness of the belt. A combination of belt, sheaves

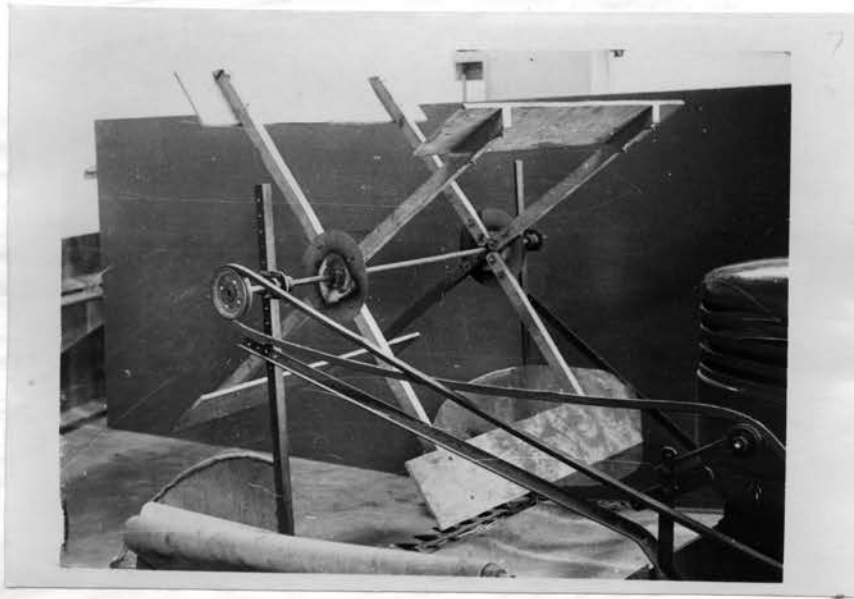


Fig. 7. Reel, Reel Supports and Bearings

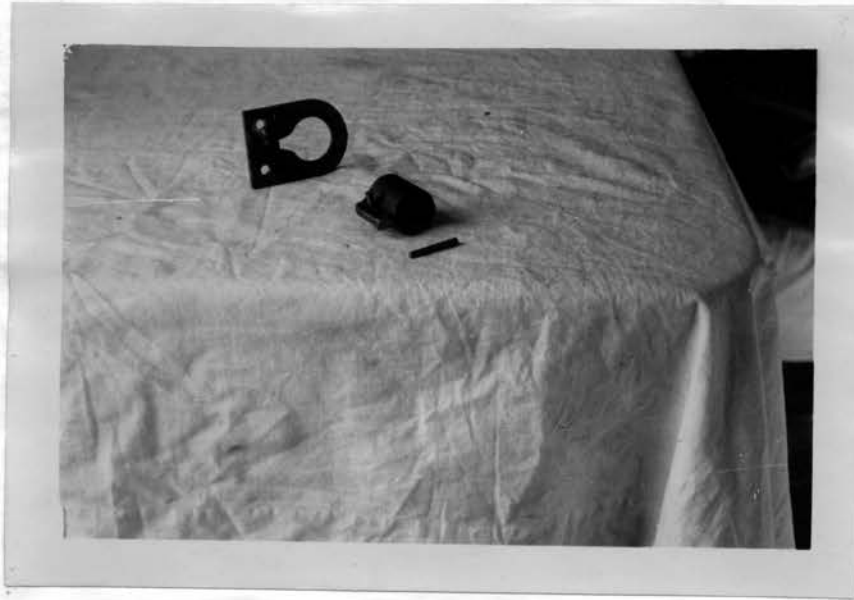


Fig. 8. Parts of the Self-Aligned Bearing

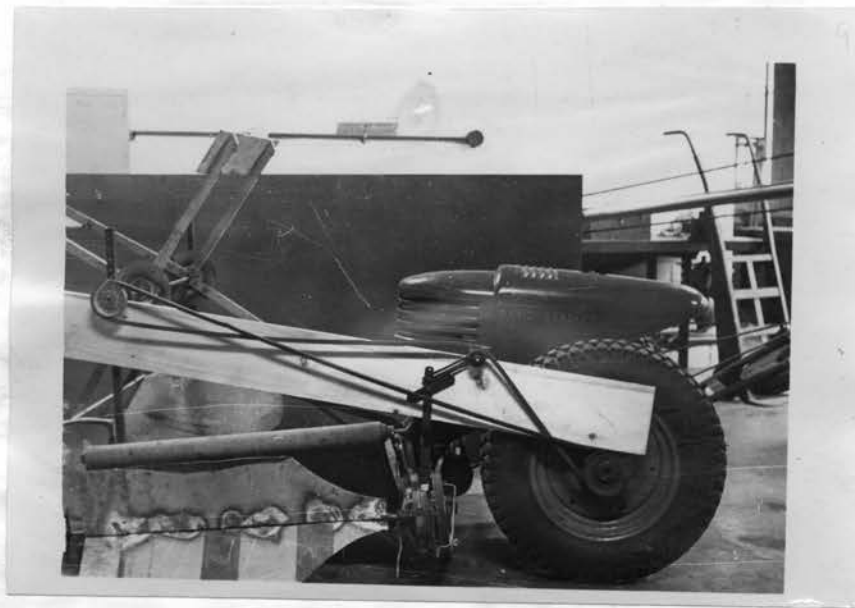


Fig. 9. Reel Drive



and idler-pulley transmitted the power to the reel, as shown in Figure 9.

The speed of reel is still an essential feature. If it is excessive, ripe grain may be threshed out by the slats; if too slow, cut grain may fall on or ahead of the sickle and choke it. The peripheral speed of the reel in the McCormick Deering combine No. 42 is 750 feet per minute. The diameter of the reel in this designed reaper is 47 inches; its R.P.M. will have to be about 61.

$$2 \pi RN = 750$$

$$N = \frac{750}{2 \pi R} = \frac{750 \times 12}{2 \times 3.1416 \times 23.5} = 61$$

R = Radius of the reel (inch)

N = R.P.M. of the reel

$$\pi = 3.1416$$

Transmission of power to sickle, roller of canvas conveyor, basket and reel

The various parts which transmit the power to the sickle, roller of canvas apron, basket and reel are described and shown by figures as follows:

1. Transmission of power to the sickle

(a) Crankshaft (Fig. 10-A) and crank (Fig. 10-B).

The power was transmitted from the engine of the tractor to the crankshaft by V-belt (not shown). At one end of the shaft a crank was welded. The

crank carries the wristpin to which the pitman (Fig. 10-C) is attached. The crank shaft runs at speed of 400 R.P.M. Table 9 (Ramiah, p. 51, 1947) indicates the important dimensions, the R.P.M. of the pitman shaft, the linear speed of the sickle bar, and the number of strokes of the sickle bar per foot of travel of the land wheel. All the features of the cutter bar in this designed reaper were very similar to that of the combine No. 42 in Table 9.

(b) Jaw clutch (Fig. 10-D). Jaw clutch was used for stopping and starting the work of harvesting. Jaw clutch is controlled by the clutch fork and the clutch fork is operated by a small lever near the handle of the tractor.

(c) Pitman and bell crank. The pitman (Fig. 10-C Fig. 11-A) connects the wristpin of the crank and the bell crank (Fig. 11-B), and the bell crank connects the cutting knife or sickle. The pitman changes the revolving motion of the crank into a reciprocating motion, which it transmits to the sickle. The pitman was made of wood. Wood is light and resilient. The pitman is held in place on the wristpin by a latch. It may be easily removed when it is necessary to change the

Table 9

## Comparative Statement of Speeds of Sickle Bars in Harvesting Machines

| Name of machine   | Type  | Width of cutter bar | Assumed speed of wheel | R.P.M. of wheel | Speed increase at ratio between wheel and pitman shaft | R.P.M. of shaft | Linear speed of pitman | Speed of sickle bar | No. of strokes of sickle bar per ft. of land |
|---|---|---------------------|------------------------|-----------------|--|-----------------|------------------------|---------------------|--|
|   |   | in                  | in                     | MPH             |  |                 | ft/sec                 |                     |  |
| New Model No. 4 McCormick Deering side-cut mowing machine | Two-horse drawn                                 | --                  | 33                     | 2               | 20.5   | 27              | 550                    | 4.6                 | 6.2  |
| David Bradley rubber tired side-cut mowing machine        | Two-horse drawn                                 | 60                  | 27.5                   | 2               | 25.0   | 24.5            | 612                    | 5.05                | 6.8  |
| National Mowing Co. hand mower (engine operated)          | 1.5 H.P. Briggs and Stratton 4 cycle gas engine | 40                  | 12                     | 2               | 56   | 13.5            | 756                    | 4.2                 | 8.33   |
| Two tractor mowers  | --  | --                  | --                     | 3               | --   | --              | 795                    | 6.6                 | 6.0  |
| Data given by L. F. Larson                                | Horse-drawn converted to tractor mowers         | --                  | --                     | 3               | --   | --              | 890 to 880             | --                  | --   |
| McCormick Deering combine No. 42                          | Power take-off drive                            | 48                  | 26                     | 3               | 39   | --              | 400                    | 3.34                | 3.0  |



Fig. 10. The Driving Arrangement  
A. Crankshaft  
B. Crank  
C. Pitman  
D. Jaw clutch



Fig. 11. Transmission of Power to the Sickle  
A. Pitman  
B. Bell crank

machine parts. The opposite end of the pitman connects the pitman box fitted on the bell crank.

2. Transmission of power to the roller of the canvas conveyor

(a) A pair of bevel gears (Fig. 12-A). The bevel pinion is keyed to the right end of crankshaft and the bevel gear is keyed to shaft of the roller. The speed ratio of the bevel pinion and the bevel gear is 2 to 1. Then the shaft of the roller runs at 190 R.P.M. The diameter of the wooden roller is 2-1/4 inches. Then the speed of the canvas apron running around the roller is about 120 feet per minute (check with the data in Table 8).

These bevel gears are used for changing the direction and speed of the motion, the crankshaft being placed at a right angle with the roller's shaft. They are protected with a fence which is shown in Figure 1, No. 21.

3. Transmission of power to the basket

The problem was to get the basket to rotate 120 degrees to unload the cut grain after a certain amount of cut grain was collected. When this project was first undertaken there were several diverse designs and arrangements proposed. Several of these were given consideration and tested





Fig. 12. Transmission of Power to the Roller  
A. Bevel gears  
B. Wooden roller

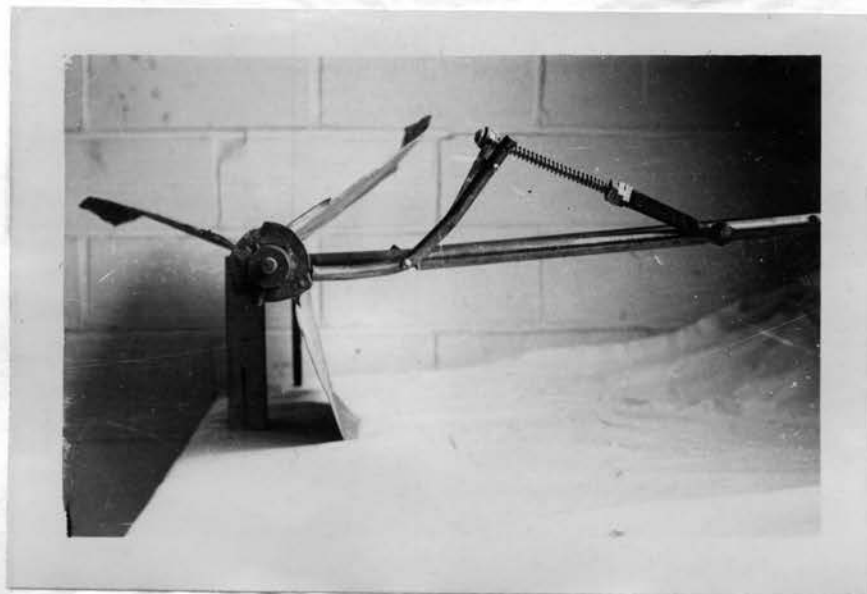


Fig. 13. The Turning of a Basket Automatically Controlled  
by the Weight of Cut Grain

before one was finally adopted. Each one of these designs excelled in some special point, but was thrown out on account of an objectionable point which overruled the good points. The design having the best combination of controlling factors was experimentally arrived at:

(a) In the first experiment the weight of collected cut grain, cam and spring (Fig. 13) were used. As the weight of collected cut grain in the basket overcame the strength of the spring, the basket turned 120 degrees until the next notch of the cam approached the nose of the rod which was controlled by the spring.

This method was discarded for it could not work successfully. In fact, the resistant force included not only the strength of the spring, but also the frictional force of the contact surfaces between the shaft of the basket and the bearings, and between the nose of the rod and the cam. Within these resistant forces the frictional force varied always on account of the vibration of operating conditions and the different smoothness of rubbing surfaces. If any one force varied, it made the experiment fail to get the desired result.

(b) In the second experiment the Geneva wheel (Pragman, p. 241, 1947) was used. The derivative type of Geneva wheel is shown in Figure 14. The disc A with pin is the driver. The pin moves in the slots on B, causing B to turn. B is fastened to the shaft of the basket. In the figure, B will turn one-third revolution (or 120 degrees) and rest while A makes one continuous revolution. During the period of rest B is prevented from turning, since its concave surface is in contact with the convex surface on A. This method was discarded too, because after turning one-third of a revolution and when the basket should stop and unload, B received an inertia from it and made it continue to turn. Meanwhile, a large pressure took place on a point, or a small contact area, between the concave and convex surfaces and had a tendency to stop A from continuing to turn. In this way the machine parts of this mechanism were easily out of order.

(c) The third experiment resulted in the adopted design. The design which was finally accepted as the best arrangement to use is the ratchet mechanism (Pragman, p. 243, 1947). The arrangement is shown in Figure 15. A and A' are fastened

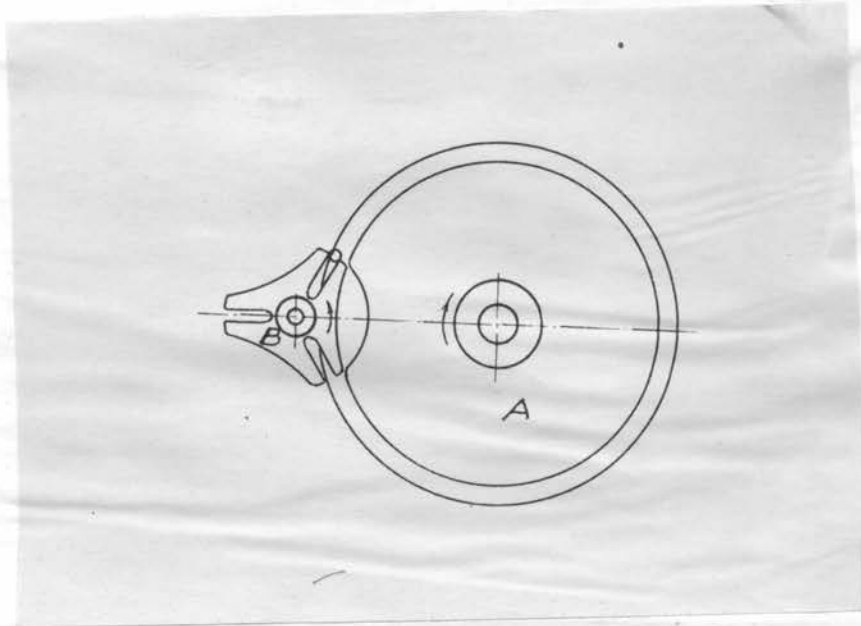


Fig. 14. Transmission of Power to the Basket by Use of Geneva Wheel

to the shaft of basket. A, the front 3-teeth ratchet wheel and A', the rear 3-teeth ratchet wheel, are fastened together but with opposite teeth direction and B is an oscillating lever carrying the driving pawl C. C is connected with a revolving sheave E by rod F. A supplementary pawl D prevents backward motion of the wheel. When arm B moves counter-clockwise, the pawl C will force the wheel through a fractional part of a revolution (say 120 degrees) depending upon the motion of B. When the arm moves back, the pawl C will slide over the surface of the ratchet wheel while the wheel remains at rest because of the fixed pawl D and will be ready to pull the wheel on its forward motion as before. But the motion imparted to the wheel is usually so great that the wheel (A and A') may over-travel; that is, it may continue to move after the pawl C has ceased to drive. Another pawl G prevents the forward motion of the wheel by touching one tooth on wheel A'. In this way, when arm B moves clockwise before pawl C forces the wheel to turn, pin F (riveted to B) will push G to release first. The sheave E receives power from a pulley fastened to the shaft of the outside roller by a V-belt. The speed of E is 30 R.P.M.



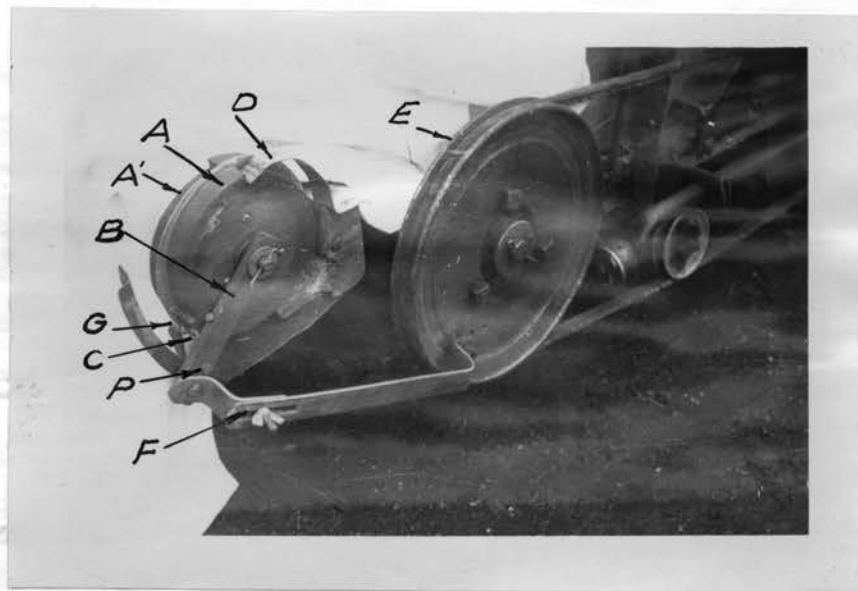


Fig. 15. Transmission of Power to Basket by Use of Ratchet Mechanism

### Dividers

An inside divider and an outside divider (Fig. 1, No. 5) were used. Both were made of sheet iron and were braced from the main frame. Each one projected twelve inches into the standing crop separating it in advance of the cutter. The dividing functions are always to gather and direct the grain at the inner and outer edge of the swath toward the sickle.

### Shoes

The height of cut was regulated by these two shoes. Shoes were fastened under the cutter bar by two different bolts. As it was the purpose in this machine to effect a cut as close to the ground as possible, for the straw was to be used later. The adjustment of the height of the cutter bar above ground level was found unnecessary. The shoes made by low carbon steel are shown in Figure 16.

### Balancing weight

A piece of cast iron casting weighing about 50 pounds (Fig. 1, No. 20) was fastened to the handles of the tractor for balancing. The balancing weight facilitated handling.



Fig. 16. Two Steel Shoes

### FIELD TRIALS

Before trials were made in the field, all the parts were checked for proper assembly, the bearings were greased, and canvases were tightened and squared. The experimental machine was tested in the laboratory first. The engine was started and the hand levers were put on. All the moving parts, such as jaw clutch, sickle bar, rollers, canvas conveyors, basket, and reel were set in motion. These instituted mechanisms functioned satisfactorily. A field trial was taken on August 18, 1948, in the oat field on the Experimental Farm of the Department of Agricultural Engineering. Oats were considered as equivalent to rice or wheat in the conditions of the shearing of the stems. The date seemed a little later than the regular harvesting season. The straw was overdried, all grains were shelled out, and a lot of weeds, about one foot high, grew in the oat field.

The cutting mechanism operated smoothly for only a few minutes, then clogged. A noticeable slippage of the power-transmitting belt over the V-pulley (the pulley fastened on the middle part of the crankshaft) took place. After the belt was adjusted and tightened the same trouble occurred at the second operation. After inspection, the cause of slippage was found to be, not because the sickle was clogged, but

because the rollers were wound with the many weeds. Most of the green cut weeds entered under the canvas conveyor instead of lying on the surface of it and wound around the circumference of the rollers, gradually increasing their size. The rollers could continue to run until the size increased to the largest case. The would weeds pushed the canvas conveyor out to touch the sheet iron (the bottom of the platform) and caused much friction between the sheet iron and the canvas conveyor and stopped the moving conveyor. The conveyor stopped the roller, the roller stopped the transmitting mechanism and the transmitting mechanism finally stopped the engine. This evidently showed that it was necessary to set two boards (Fig. 17) separately under the two sides of the upper half of the canvas conveyor to prevent weeds entering in.

The reel and basket worked successfully. Only the height of the basket seemed too low in position. It was easy for the outer edge of the basket to touch the ground. This experiment showed that the basket should be fixed at such a height that the lowest part will be six inches above the ground.

The height of shoes under the cutter bar was just ideal; the cutter bar was four inches above ground level.

A second field trial was made on September 2, 1948 at the same place. No cut weeds entered under the canvas





Fig. 17. Two Wooden Boards



Fig. 18. The Reaper during the Field Trial

conveyor. After reaping a certain distance, the cutter bar, canvas conveyors and basket ceased to work, but the engine still ran. The belt slippage existed on the same pulley which was put on the center part of the long crankshaft. The crankshaft which was made of steel tubing was supported by two bearings at both ends. Although it had adequate strength to transmit the imposed torque, it was not stiff enough to resist bending. Adding a bearing at the center part of the crankshaft beside the pulley to resist bending was necessary.

The third field trial was continued on October 18, 1948. This trial revealed that the working conditions would fulfill the expectations of the design. Only the cut grain conveyed by the conveyor could not drop into the basket with even butts and so it was not easy to get bundles dropping at equal distances on the ground (Fig. 18), but this might be caused by the following reasons:

The oats standing in the field were over-ripened, shelled out, or light weight and of short length (about 16 inches high). During reaping the cut grain waved because of the moderate wind and when cut and carried on the conveyor to the elevated position or the inclined plane of the outer canvas conveyor, it had a great tendency to be blown off by the wind. It might be better to use upper and lower conveyors (usually used in binder) instead of the outer

conveyor of this machine to transport the cut grain to a higher place and thus repel the effect of the wind.

## DISCUSSION

1. Some expected satisfactory features of the experimental reaper.

In the course of design of this experimental machine, the following advantages were expected; that

- a. the 1.5 H.P. David Bradley tractor would supply enough power for traction and reaping;
- b. the cutter bar and its driving arrangement would do as nice a job as that of a mower, binder, or combine;
- c. the outer canvas conveyor, as well as the elevators of grain binder, would elevate the cut grain to a predicted height;
- d. the basket would definitely turn at the 120 degrees angle after a certain time interval;
- e. the four-inch height of the shoes would help the sickles cut the crop at the right place;
- f. only a jaw clutch would control the whole reaper and add simplicity to the operation of the machine.

2. Two uncertain features of the experimental reaper:

- a. The device of gathering the cut grain into bundles of even butts and heads.
- b. The device of depositing the bundles of the

gathered cut grain on the ground at equal spacing.

Suppose that the crop, oats, reaped by this machine, grew during a normal harvesting season, that it had the right height and weight, then the cut grain might be gathered into bundles of even butts and heads, and deposited by the basket on the ground at equal spacing. Proper weight and height fitted the designed functions of the machine and might overcome the weather conditions unfavorable for harvest.

### 3. The capacity of the reaper

According to the following equation given by E. C.

McKibben (1930) the capacity of this reaper was 9 acres.

$$A = SW = \frac{36}{12} \times 3 = 9$$

A = actual capacity of machine per day in acres

S = rate of travel in miles per hour

W = width of machine in feet

This result was comparable to the performance of grain binders and was certainly many times that of a hand sickle.



## SUMMARY

1. The purpose of this research was to design a reaper to be used for harvesting rice and wheat under the Chinese agricultural conditions and that could be drawn by a small tractor.

2. Only the small tractor used as the power unit can meet the need of small farms in China.

3. About 48 percent of the food supply in China is rice and wheat. There is a greater shortage of labor during the harvesting season of rice and wheat than for any of the other farming operations.

4. A reaper is needed but one has not yet been designed that can be attached to any kind of a small tractor.

5. A reaper for this use under Chinese conditions must be able to cut the stalks off about three to four inches above the ground level, to gather the cut stalks into bundles (not in tied bundle) of even butts and heads, and to deposit them on the land beside the machine at regular intervals.

6. Field trials were made to show the satisfactory performance of the designed reaper, the work of the reel of the cutting mechanism, and of the canvas conveyors for elevating the cut grain to the top of the basket.

7. The irregularity of the dropping of the cut grain into the baskets causing uneven bundles of butts and heads might have been caused by,

- (1) lack of weight in the over-ripened cut grain
- (2) the wind blowing the over-dried, light, cut grain into disorder.

8. The suggestion is made by the author that further studies in collecting and depositing the cut grain into bundles by the basket shall be made under more favorable harvesting conditions.

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